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RESEARCH ARTICLE

Forest–grassland biodiversity hotspot under siege: land conversion counteracts nature conservation

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Abstract. We report extent and rate of land use/land cover change in a forest–grassland mosaic of Rio Grande do Sul, Brazil, during a recent period of increasing conflicts between native habitat protection and conversion. The area is part of the Atlantic rain forest biome, a Global Biodiversity Hotspot. Analyzing Landsat and Google Earth imagery, and calculating an effective conservation risk index (ECRI) as ratio of converted to remnant area, we specifically compared the effectiveness of designated fully protected areas (FP-PAs) and Sustainable Use areas (SU-PAs) in preventing conversion of native forest and grassland habitats for agri- and silviculture, relative to areas outside. Grassland area decreased by 17%, corresponding to a net loss of 59,671 ha, in the entire area. Forest gains exceeded losses, and ECRI was zero inside Full Protection PAs. Non-native tree plantation area increased by 94% over the entire study area; cropland increased by 7%. Conversion for silviculture predominated outside the designated PAs and conversion for agriculture predominated inside the designated PAs. ECRI was generally higher for grassland than forest, and in SU-PAs, grassland ECRI was several times higher than in areas without any protection status. These developments are in stark contrast to the high standards of the Brazilian protected area system and corresponding International Union for Conservation of Nature and Natural Resources categories. They are due to protracted regularization of land conversion and establishment of designated protection areas. Furthermore, they reveal the dilemma of previously managed grasslands in strictly protected areas being eventually succeeded by forest, and the hazards of broad interpretation of the term "sustainable development".

Key words: *conservation risk; protected area; strict protection; sustainable use; temperate grasslands.*

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Introduction

The Atlantic Forest biome of Brazil supports a variety of terrestrial ecosystems, from tropical to subtropical dry and moist forests to savannas, shrublands, and grasslands. The biome has been included among the world's biodiversity hotspots (Myers et al. 2000, Mittermeier et al. 2011), i.e., areas featuring "exceptional concentrations of endemic species and experiencing exceptional loss of habitat" (Myers et al. 2000). Its southern highland portion was, until the arrival of European settlers in the 16th century, characterized by a mosaic of primary grasslands and *Araucaria* broadleaf forests.

Of these two major vegetation types, the *Araucaria* forest was reduced by logging to a mere fraction of its original extension (Leite and Klein 1990), especially for timber export in the 20th century. Its name-giving species *Araucaria angustifolia* was recently placed in the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Endangered Species (Thomas 2013). Efforts of legally protecting ecosystems in Brazil and in Rio Grande do Sul were initially directed to greater extent at forests than non-forest vegetation types, in reaction to such devastating exploitation; the major nature conservation law still bears the name "Código Florestal", Forest Code.

The natural grasslands of southern Brazil, on the other hand, provisioned large forage areas for cattle, sheep, and horses, introduced in the 17th century. Their flora has a transitional character of tropical and temperate plant lineages with a high proportion of endemic species (Iganci et al. 2011); 1,161 vascular plant species were registered for highland grasslands by 2009 (Boldrini et al. 2009), and inventories are still ongoing.

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Notably, the grassland area of the entire state of Rio Grande do Sul had already been reduced by approximately half between 1974 and 2002 (taking into account grasslands contained in the Pampa and Atlantic Forest biome; Cordeiro and Hasenack 2009).

Expansion of tree monocultures started in the late 1980s, when the federal state began to compete with Argentina and Uruguay in attracting international investors from the cellulose industry (Gautreau and Vélez 2011). Agricultural land use, particularly soybean cultivation, accounted for marked grassland losses in the central highland of Rio Grande do Sul.

In the north-eastern highland grasslands of Rio Grande do Sul, the *Campos de Cima da Serra*—contained in the Atlantic Forest biome—land-use changes were slower to arrive. Traditional pasture management in this region includes burning native grasslands at the end of winter, which was discouraged by enforcement of a statewide legal ban on fire (State Law number 9.519/1992, Rio Grande do Sul State Nature Conservation Law; http://www.mprs.mp.br/ambiente/legislacao/id606.htm) especially in the past decade.

At the same time, the need to include grassy biomes and vegetation types in nature conservation efforts came into focus at both national and international level. Hoekstra et al. (2005) calculated a conservation risk index (CRI) for the world's major biomes as the ratio of per cent area converted to per cent area "protected" inside designated conservation units, as listed in the World Database of Protected Areas. They highlighted a particularly high conservation risk for temperate grasslands.

In 2006, for the first time, the southern Brazilian highland grasslands were explicitly named as worthy of protection within the Atlantic Forest biome (Federal Law 11.428/2006, on the use and protection of native vegetation in the Brazilian Atlantic Forest biome; http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11428.htm). In 2008, the World Conservation Congress called on the governments of Argentina, Brazil, and Uruguay to "include in their agendas the development of actions for the conservation and sustainable use of natural grasslands and to raise public awareness of their importance" (IUCN 2008), and Brazilian scientists further urged lawmakers and nature conservation authorities not to neglect protection of grassland and other non-forest ecosystems (Brandão et al. 2007, Overbeck et al. 2007, Ab'Sáber 2010).

In summary, the 6-year period investigated in this study (2002/2003–2008/2009) witnessed a clash of multiple interests. Policy favored land use conversion over traditional land use; at the same time, the government and the public became aware of conflicts between grassland conservation and land use on one hand, and grassland and forest conservation on the other hand. What was the outcome in the hitherto comparatively well-preserved *Campos de Cima da Serra* region? To which extent were native grassland and forest transformed to anthropic land use/land cover (LULC) classes, particularly for silvi- and agriculture, and did native vegetation recover in other areas?

Specifically, we compare these developments inside and outside designated protected areas (PAs in the following). Nature conservation areas are named as a "cornerstone of efforts to halt the loss of biodiversity" (Mittermeier et al. 2011:18)—given their effective establishment and management. However, conversion may occur inside designated PAs and management may be inefficient inside established PAs. The Conservation Risk Index proposed by Hoekstra et al. (2005), its merit in pointing out conservation priorities notwithstanding, obscures this fact.

IUCN and Brazilian Law distinguish, moreover, between PAs designated to Full Protection, and to Sustainable Use. Brazilian Federal Law 9.985/2000 (Art. II, XI) defines "sustainable use" as exploiting the environment in such a way that continuity of renewable environmental resources and ecological processes is ensured, that biodiversity and other ecological attributes are maintained, and that it is socially just and economically viable. The major challenge of deciding which resources can be used by whom, and which forms of use are sustainable (Rylands and Brandon 2005) rests, ultimately, with the administrators of these units. To the best of our knowledge, there is no published assessment of the practical implications, i.e., the effectiveness of Protected Areas assigned to Full Protection (FP-PAs), and to Sustainable Use (SU-PAs), in preventing conversion of original vegetation. To fill this knowledge gap, we propose an effective conservation risk index (ECRI) as ratio of converted to remnant area inside and outside designated PAs.

Material and Methods

Study area

The study area is located in the *Campos de Cima da Serra* (subtropical highland grasslands) in the north-eastern part of the federal state Rio Grande do Sul, Brazil (Fig. 1).

The climate is humid temperate with warm summers and no dry season (Köppen type Cfb). Precipitation is high and evenly distributed throughout the year (annual average between 1,500 and 1,700 mm, maximum 2,500 mm in some subregions). The average annual temperature ranges from 14 °C to 16 °C, with the coldest temperature occurring in July (10–12 °C) and the highest in January (24–27 °C) (Almeida 2009).

The *Campos de Cima da Serra* are dominated by effusive basaltic rocks on which brown soils (Cambisols) develop. The relief is undulating and elevation increases in eastern direction to a maximum of 1,293 m at the eastern edge (Rönick 1981). The original vegetation consists of mosaics of grasslands (*Campos*), shrub lands, and forests

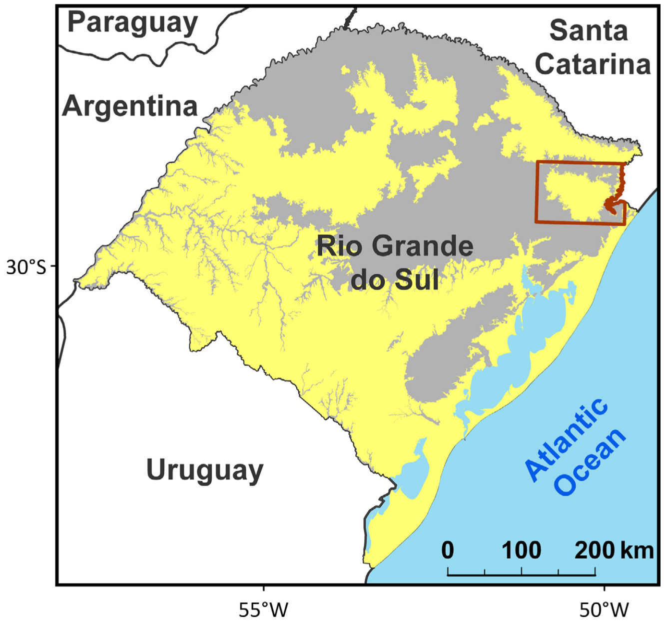

Fig. 1. Location of the study area (red frame) on the Campos de Cima da Serra in Rio Grande do Sul, Brazil. Yellow: grass-dominated vegetation, extension in 1976 (modified from IBGE 2004).

(mainly dominated by *Araucaria angustifolia*) (Leite and Klein 1990).

Pines, mostly *Pinus elliottii* and *Pinus taeda*, native to North America, are preferred in commercial plantations in the study area. Common crops are potato, maize, and cabbages, often rotated with exotic forage crops (cultivars of *Lolium*, *Holcus*, *Avena*, *Trifolium*, and *Lotus*, originally native to Eurasia) for spring cattle grazing (Nabinger et al. 2000).

Seven designated nature Protected Areas are located within the study area. National Park "Serra Geral" serves as an extension of National Park "Aparados da Serra", thus, counting these areas as one, three protected areas are assigned to Full Protection and three to Sustainable Use (Table 1). Full protection, according to Federal Law 9.985/2000, allows only for such use of natural resources that involves no damage or harvest; alterations to the ecosystem by human interference must be avoided. Although these PAs were designated 18 to 66 years ago, land acquisition by federal and state authorities is still ongoing (D. Zimmermann and D. Slomp, *personal communication*; see also Silva 2005). In SU-PAs, where the aim is to "reconcile nature conservation with sustainable use", restrictions are less severe.

Typically, FP-PAs under national governance cover larger areas than those under federal state governance, and state-governed SU-PAs cover areas several times larger than state-governed FP-PAs (Rylands and Brandon 2005). These trends are well represented in the study region (Table 1). As a peculiarity, SU-PA "Rota do Sol" encloses FP-PA "Aratinga" on all sides (Fig. 2), one of its purposes being to act as a buffer zone for the latter (http://www.sema.rs.gov.br/).

Appendix S1: Table S2 lists in more detail the purpose of the different types of protected area according to Brazilian Law, the corresponding IUCN categories of protection (Rylands and Brandon 2005, Silva 2005) and the objective of these categories according to Dudley (2008).

Remote sensing analysis

In the years 2012 and 2013, four Landsat 5 images (sensor: Thematic Mapper) were used to detect LULC change in the study area: Images path/row 221/080 of May 13, 2002 and October 3, 2008, and path/row 220/080 of September 4, 2003 and August 28, 2009, respectively. Landsat T 5 and 7 images from the autumn months of 2008 and 2009 were chosen for low contamination of clouds. Landsat 8 was still in test so that more recent images could not be considered. However, the resulting 6-year observation period was considered

Table 1. Protected area type, category, name, and area contained inside the study area *Campos de Cima da Serra*. Objectives of the different categories are listed in Appendix S1: Table S2.

Purpose and category†	Name	Area (ha)	Year designated	Sum (ha)
Full protection				29,002
National Park	Parque Nacional da Serra Geral‡	8,540	1992	
National Park	Parque Nacional dos Aparados da Serra	7,708	1959	
State Park–RS	Parque Estadual do Tainhas	6,643	1975	
Ecological Station–RS	Estação Ecológica Estadual Aratinga	6,111	1997	
Sustainable use				50,625
National Forest	Floresta Nacional de Canela	562	1968	
National Forest	Floresta Nacional de São Francisco de Paula	1,611	1968	
Environmental Protection Area–RS	Área de Proteção Ambiental Rota do Sol	48,452	1997	

†RS indicates under governance of federal state Rio Grande do Sul; others under national governance.
‡Practically an extension of National Park Aparados da Serra; total area of both parks roughly twice as large as shown here (http://www.icmbio.gov.br).

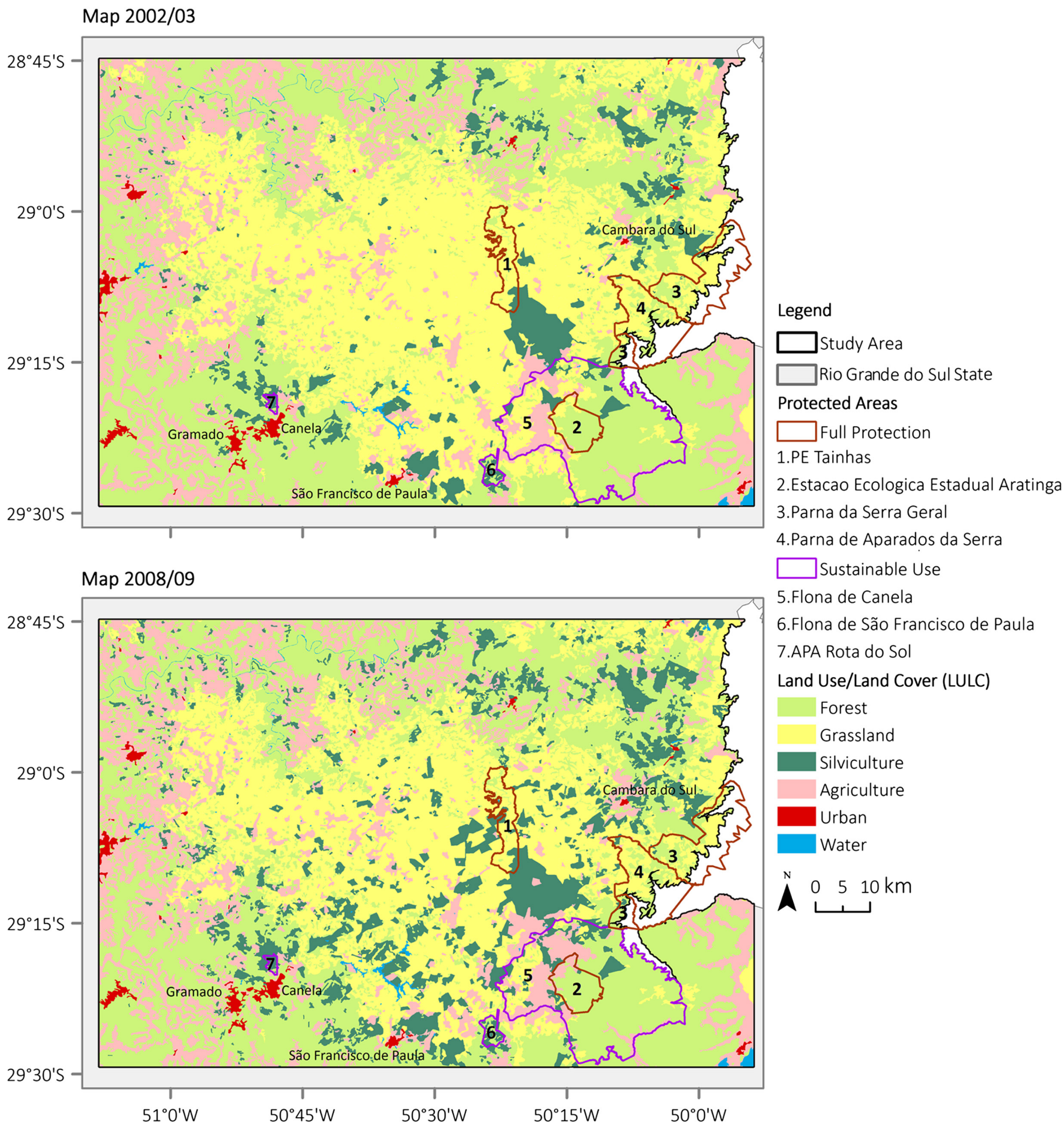

Fig. 2. Map of LULC in the Campos de Cima da Serra in 2002/2003 (top) and 2008/2009 (bottom).

sufficient to detect significant trends in land use change, given the economy and politics scenario at the time.

The methodology was based on Cordeiro and Hasenack (2009), who mapped 15 LULC classes in the study area by visual on-screen interpretation of the same 2002/2003 Landsat images. For this study, these 15 classes were merged into six in order to emphasize major changes: forest, grassland, water, urban, agriculture, and silviculture (Appendix S1: Table S1).

False-color Landsat images with RGB composition 453 were used for mapping silviculture and forest vegetation with mostly continuous vegetation cover; false color images with RGB composition 543 gave best results for mapping permanent herbaceous vegetation and arable land (i.e., with some cover of bare ground). (Spectral channels: (3) red (0.63–0.69 μm); (4) VNIR (visible and near-infrared, 0.76–0.90 μm); (5) SWIR (short wave infra red, 1.55–1.75 μm).) Visual interpretation of the 2002/2003 Landsat images was originally validated by extensive groundtruthing performed by H. Hasenack and collaborators. Both 2002/2003 and 2008/2009 LULC maps were validated by comparison with high-resolution historical imagery available for the period between 2002 and 2009 from Google Earth (Google Inc.). Although the study region is poorly covered in the earlier years, images from one to two dates within the observation period are available for most of the area. Nearly all are Quickbird images, with a resolution of 2.44–1.63 m (Digital Globe), and dates between late autumn and winter. While qualitative validation was found to be satisfactory, we also calculated overall accuracy (see Pontius and Millones 2011) of LULC identification on the basis of LANDSAT and high-resolution images, using a random sample of 100 points across the study area. It is 76% for the 2002/2003 LULC maps and 71% for the 2008/2009 LULC maps.

Satellite images were vectorized on screen at a scale of 1:50,000, using a minimum mappable area of 6.25 ha. The LULC polygons were drawn in CartaLinx (Clark Labs) and exported as shapefiles to ArcGIS 10.1 (ESRI). In the follow-up mapping, we used the map produced by Cordeiro & Hasenack as basemap to vectorize only areas in which LULC change from the 2008/2009 mosaic was detected. For change analysis, both vector files were rasterized at 30 m resolution. Data were displayed and analyzed using the coordinate system Universal Transverse Mercator (UTM) Zone 22, datum WGS84.

Shapefiles for designated Protected Areas (state of the year 2005) were generated by the Brazilian Environment Ministry. Comparisons of LULC change inside and outside PAs refer to a total area of 858,963 ha outside and 79,627 ha within official designated borders of these units. Changes in LULC within and between the six classes inside and outside PAs were calculated and displayed with ArcGIS 10.1 (ESRI) and in a cross-tabulation matrix.

Following the methods outlined by Pontius et al. (2004), we examined the cross-tabulation matrix to assess the total change of LULC classes between 2002/2003 and 2008/2009, and to calculate the relative abundance of land cover classes throughout the study area to determine if changes are more or less frequent than "expected by chance" (EBC). We maintain this terminology for consistency with Pontius and colleagues in spite of a certain ambiguity: Conversion to arable land and tree plantations does not occur by chance but is an intentional human act. In a strictly protected unit, no conversion at all should occur and thus, any rate of change must be larger than expected by chance. The method does, however, point out which LULC types are more likely to be subjected to such change than others.

Furthermore, we quantified endangerment outside PAs and inside SA- and FP-PAs by calculating an effective conservation risk index (ECRI) as ratio of converted area (i.e., on which original grassland and forest was transformed to cropland or tree plantations) to remnant grassland or forest area (Fig. 3). "Remnant" is that area of a given class that did not change between the image dates. By definition, in strictly protected units, ECRI should be zero.

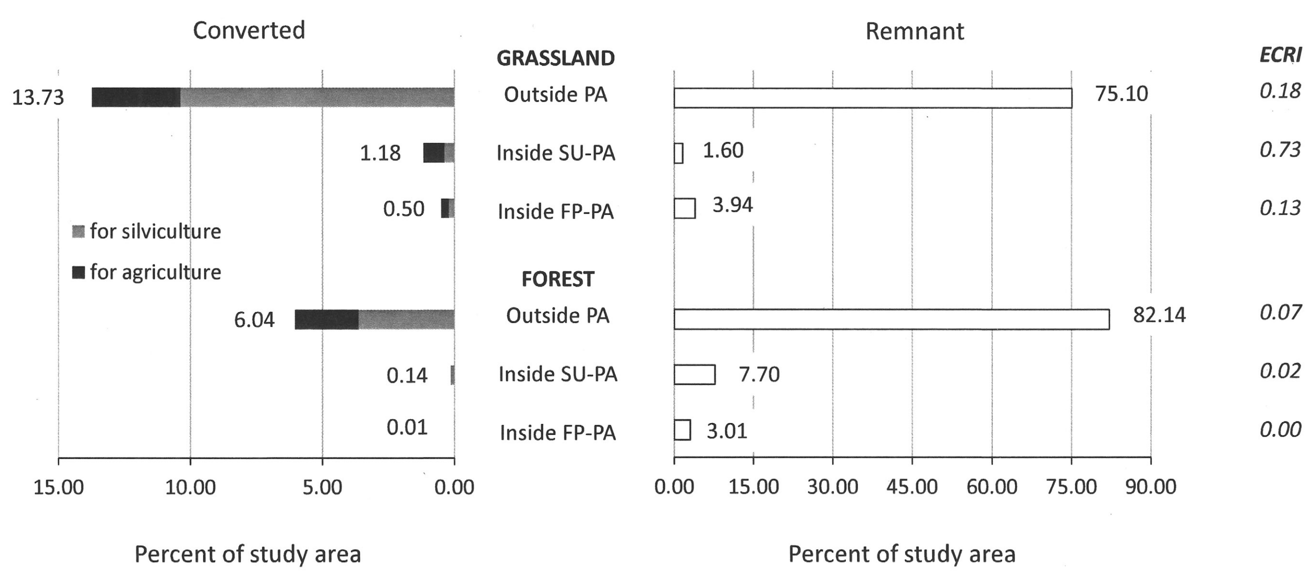

Fig. 3. Conversion and conservation of native vegetation outside and inside designated protected areas (PAs) in the study area Campos de Cima da Serra. SU: Sustainable Use. FP: Full Protection. The effective conservation risk index (ECRI) was calculated as the ratio of per cent area converted for silvi- and agriculture between 2002/2003 and 2008/2009 to per cent of area remnant in 2008/2009 (area here refers to total area covered by forest or grassland in the study region; compare Hoekstra et al. 2005). Note different x axis scales of graphs.

Results

In the years 2002/2003, near equal proportions of the study area were covered by forest and grassland (38.8% and 36.7%, respectively); 23.5% were covered by the anthropic LULC classes agriculture and silviculture, while minor proportions of land had urban and water cover. Designated SU-PAs contained 7.9% of total forest cover and 2.9% of total grassland cover; designated FP-PAs contained 3.1% of total forest cover and 4.8% of total grassland cover.

In the following 6 years, in the entire study area, silviculture increased from 55,518 ha to 107,819 ha, i.e., expanded by 94% relative to the area occupied in 2002/2003. Expansion of agriculture occurred on 12,120 ha, i.e., increased by 7% total.

Grassland was the main target for conversion to these anthropic LULC classes (Fig. 3). Effective conservation risk index (ECRI) was generally higher for grassland than for forest, irrespective of protection status. Inside SU-PAs, grassland ECRI was several times higher than outside designated PAs. Inside FP-PAs, grassland ECRI was lower than outside designated PAs, but still clearly above zero. Forest ECRI, on the other hand, was practically zero inside FP-PAs, and nearly zero in SU-PAs (Fig. 3). Outside PAs, the strongest signal of systematic change that also affected largest proportions of the area was of conversion of grassland for silviculture. Inside PAs, the strongest signal of systematic change was of conversion of grassland for agriculture (Fig. 4).

In detail, conversion of grassland to silviculture occurred on 4.2% of land area outside PAs (rates of conversion 2.6 times >EBC), and on 2.6% and 2.7% of area in SU-PAs and FP-PAs, respectively (rates of conversion 1.6 and 1.5 times >EBC) (Fig. 4). Forest conversion for silviculture occurred on 1.5% of the area outside conservation units (rates of conversion 1.9 times >EBC), and on 0.9% of the area inside SU-PAs (rates of conversion 1.8 times >EBC) (Fig. 4).

There was no strong signal of either grassland or forest conversion for agriculture outside designated PAs. Inside SU-PAs, grassland conversion for agriculture occurred on 5.5% of the area at a rate three times >EBC; inside FP-PAs, on 3.3% of the area at a rate 2.9 times >EBC (Fig. 4).

Agriculture areas were non-randomly converted for silviculture throughout the study area, outside and inside designated PAs, but on relatively minor proportions of the area (Fig. 4). In both types of protected area, grassland was established on former silviculture areas, but this, too, occurred on only minor proportions of the area: 0.3% of area in SU-PAs, and 0.2% of area in FP-PAs.

Over the entire study area, net loss of grassland area amounted to 59,671 ha, being one order of magnitude higher than net loss of forest area. Relative to the total area occupied in 2002/2003, grassland decreased by 17%. Net loss of grassland was registered in all designated PAs (Table 2b). The designated FP-PAs lost a total of 1,739 ha of grassland to new tree plantations and cropland. In the Environmental Protection Area

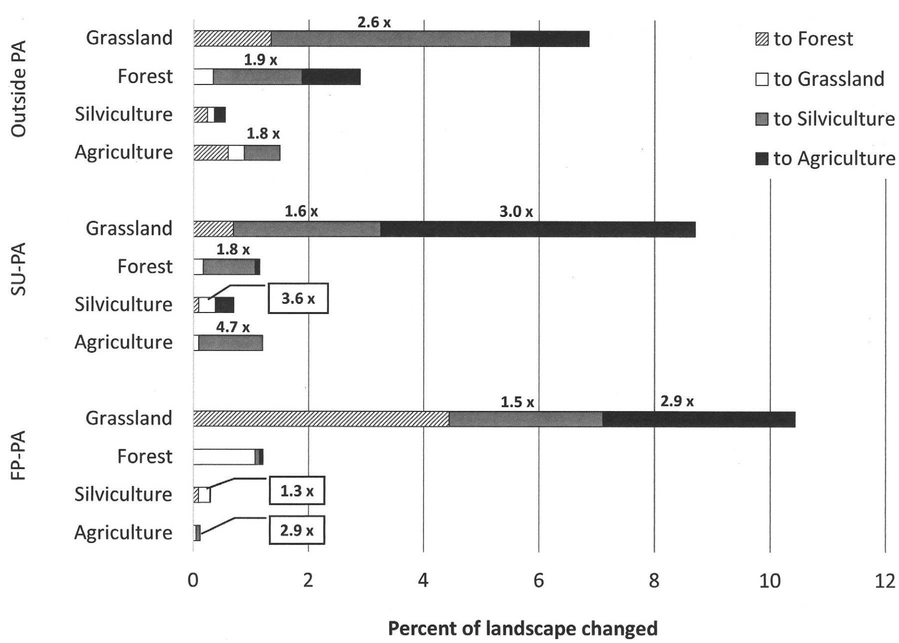

Fig. 4. Transitions between LULC classes on percent of the landscape in subsets of the study area: Area outside protected areas (PAs), area inside designated Sustainable Use-PAs and area inside Full Protection PAs (compare Table 2). Factors above bars indicate rates of change higher than expected by chance (>1).

Table 2. Change of four LULC classes between 2002/2003 and 2008/2009, outside designated protected areas (PAs), and inside PAs assigned to Sustainable Use (SU), and to Full Protection (FP). LULC classes: Forest (FOR), Grassland (GRA), Silviculture (SIL), Agriculture (AGR). (a) Change in terms of percentage of the landscape. Daggers indicate strong systematic, i.e., non-random transitions (see Pontius et al. 2004); compare Fig. 4. (b) Losses and gains given in absolute numbers, and calculated as percentage of area occupied of a given LULC class in 2002/2003. See text for clarification of terms. Corresponding cross-tabulation matrices will be provided by first author upon request.

	Outside PAs				In designated SU-PAs				In designated FP-PAs			
Change	FOR	GRA	SIL	AGR	FOR	GRA	SIL	AG	FOR	GRA	SIL	AGR
(a)												
Persistence	34.8	30.1	5.3	16.8	55.3	10.9	8.3	13.7	37.7	46.8	2.5	0.9
Gain	2.2	0.7	6.3	2.5	0.8	0.5†	4.6†	5.9†	4.5	1.3†	2.8	3.4
Loss	2.9†	6.9†	0.5	1.5†	1.1†	8.7	0.7	1.2†	1.2	10.4†	0.3	0.1†
Net change	−0.7	−6.2	5.8	1	−0.4	−8.2	3.9	4.7	3.3	−9.1	2.5	3.3
(b)												
Absolute (ha)	−6,394	−52,900	+49,615	+8,818	−186	−4,129	+1,955	+2,354	+963	−2,642	+731	+948
Relative (%)	−2	−16	+99	+6	−0.7	−41.6	+42.7	+31.3	+8.5	−15.9	+0.2	+329

Notes: Outside PAs, Urban LULC +379 ha/+6%; Water LULC +482 ha/+16%. In designated SU-PAs, Water LULC +6 ha/+45.1%; no urban LULC. In designated FP-PAs, no urban or water LULC.

(IUCN cat. VI), the largest of all PAs contained in the study area, absolute loss was more than twice as high: 1,237 ha of grassland were converted for silviculture, and 2,757 ha for agriculture.

Net increase of forest was observed in each FP-PA (Table 2b). Secondary forest was established on former silviculture areas, although only on minor proportions of land, and on former grassland: 0.7% of area in SU-PAs, and 4.4% of the area of FP-PAs (Fig. 4).

Type and degree of conversion were not solely connected to protection status; infrastructure and former conversion history obviously played a role. Silviculture expanded, most often, in a north-eastern direction in the study area (Fig. 2), especially along the state road RS 020, between the cities of São Francisco de Paula and Cambará do Sul (M. Lang, *unpublished data*). Moreover, expansion was concentrated in the vicinity of plantations already existing in 2002 (ibid.). In line with Lang's findings, afforestation predominated over expansion of cropland in the State Park (FP-PA) which had 9% silviculture and no agriculture cover in 2002/2003. Agriculture area surpassed silviculture area in the Ecological Station (FP-PA), as well as in the surrounding Environmental Protection Area (SU-PA) in 2002/2003; and conversion for agriculture prevailed over conversion for silviculture in both PAs during the following 6 years. LULC change in the National Forests (SU-PA), both of which already contained large silviculture areas in 2002/2003 (75% of land cover in NF "Canela", 52% of land cover in NF "São Francisco de Paula") was comparatively very low.

The expansion of water bodies in the study area is most likely connected to expansion of irrigated agriculture. However, total cover of water as well as urban land cover remained insignificant compared to the other four LULC classes (Table 2b), and is not discussed in the following.

Discussion

Loss of natural vegetation types and driving forces of conversion

With 17% of grassland area lost within 6 years, the rate of loss observed in this study surpasses rates formerly reported. According to Baldi and Paruelo (2008), 8.9% of the *Río de la Plata* grasslands were lost in approximately two decades; according to Cordeiro and Hasenack (2009), 50% of grasslands in the state Rio Grande do Sul were lost in approximately three decades; and Sommer and Saldanha (2012) report grassland loss by 4.9% in 24 years (1985–2009) in the municipality São José dos Ausentes, which extends into the study area.

These developments mirror world-wide trends in temperate grasslands. They have experienced higher rates of conversion than subtropical and tropical grassland types according to White et al. (2000) while at the same time receiving little legal protection (Henwood 1998). Hoekstra et al. (2005), using a conservation risk index calculated as the ratio of converted area to area contained in designated Protected Areas, pointed out greater conservation risk for temperate grasslands than for any other major biome. Our results add to these concerns, as they reveal substantial conservation risk for grassland even inside designated PAs.

Conservation perspectives are better, if only slightly, for native forest than for grassland. Larger proportions of total forest cover than that of total grassland cover are contained in designated PAs. Forested land was partly converted for silviculture and agriculture in the 6 years observed, but the absolute area converted was smaller than in grasslands. Secondary forest developed on small areas of former cropland and logged plantations, and on substantial areas of former grassland in FP-PAs, resulting in a net gain in forested area. Qualitative differences between remnant and secondary vegetation must, however, be taken into account. The rate of succession for secondary forest to develop similar diversity and community composition as remnant forest is not known. It is known that presence of perches for frugivorous birds is essential in promoting expansion of *Araucaria* forest onto former pine plantations (Zanini and Ganade 2005, Dos Santos and Pillar 2007); but supportive measures such as plantation of fruit-bearing trees are not routinely performed.

Secondary grasslands were also identified, but did not nearly match converted grassland area in size. Spontaneous vegetation on former pine plantations is significantly impoverished in plant species richness and significantly differs in composition from remnant grasslands even after a decade of succession (Koch et al., *unpublished manuscript*). Similar observations were made in Uruguay (Six et al. 2014) and Australia (Zaloumis and Bond 2011). Active attempts at native grassland restoration are rare, as for native forest restoration; among other reasons are lack of suitable techniques and commercial seed sources (Overbeck et al. 2013).

Native vegetation and its extensive use are evidently held in low regard. We propose several reasons for this. Global demand for wood, pulp, and paper products increased during the last few decades; monocultures, mainly of non-native pines and eucalypts, dominate entire regions of southern South America where fast tree growth, land availability, and inexpensive labor provide favorable conditions to produce cheap wood on a large scale (Carrere and Lohmann 1996). Likewise, governmental incentives and low export taxes promoted silviculture expansion in the federal state Rio Grande do Sul especially after 2005/2006 (Gautreau and Vélez 2011). Exotic tree species are preferred over natural, native forest stands for their fast economic return; Cubbage et al. (2007) calculated high internal rates between 9% and 17% of returns for *Pinus taeda* in southern Brazil. Perhaps not surprisingly, we observed a twofold increase in silviculture area in only 6 years. In the municipality of São José dos Ausentes, tree plantations expanded by approximately 514% in 24 years (Sommer and Saldanha 2012), i.e., at an even higher rate.

State governmental efforts to regulate the expansion of exotic monocultures lagged behind these developments. “Environmental Zoning for Silviculture” (Zoneamento Ambiental para Atividade de Silvicultura no RS—ZAS), developed to guide licensing of silviculture and to minimize damage to water and other natural resources, was established only in 2009 (Resolução CONSEMA 227/2009, which defines environmental zones to regulate silviculture expansion; http://www.fepam.rs.gov.br/biblioteca/zoneam_silvic.asp). By this time, maximum area occupation rates for silviculture had been reached in the northeast of the study area, and exceeded in the southwest (M. Lang, *unpublished data*).

Expansion of agriculture was overall lower within the studied time frame and is less readily explained. Soybean is widely planted in the central highland of Rio Grande do Sul and—in response to attractive international commodity prices—also accounts for the dramatic expansion of agriculture in the Brazilian Cerrado and Amazonian regions (Merten et al. 2010). But, at least during the first decade of this millennium, soybean crops did not perform well under the cooler and more humid climate of the *Campos de Cima da Serra* (C. P. Fogaça, *personal communication*) and nearly all arable land was planted with maize, vegetables, and forage crops.

It is reasonable to assume that the recently developed practice of alternating summer harvest crops and winter forage crops for fattening cattle, is an economically attractive alternative to traditional extensive cattle husbandry. Comparative studies on short- and long-term economic returns and other possible incentives for a shift from cattle husbandry to agriculture in the study region have, however, not been published.

New exotic tree plantations, as well as new cropland, are preferentially established on former grassland, rather than forest. For this, too, there are several possible explanations. One important reason is, certainly, that grassland lends itself more easily to conversion than forest; even more so as native forests were already largely exploited in the previous century, and are more likely to remain on less accessible or more infertile land. Second, as stated initially in this article, the value of temperate grasslands as hotspots of biodiversity in general, and their importance for the *Gaucho* culture of Rio Grande do Sul in particular, have only recently been recognized. At both national and international level, Brazil is perceived as a “forest country”, and the Brazilian society’s ecological conscience is most linked to the defense of the Amazonian and Atlantic forest (Vélez et al. 2009). Grassland valorization and conservation efforts have also suffered from the erroneous notion that grasslands originated from human deforestation of former woodland areas (Pillar and Vélez 2010). Finally, the traditional management of grassland in the highlands of Rio Grande do Sul was discouraged by a state-wide ban on fire (State Law number 9.519/1992). This law was increasingly enforced in the past 10 years as commercial pine plantations expanded in the study area.

Low efficiency of protected areas

Brandão et al. (2007) reported that in 2007, merely 2.6% of remaining grassland area (and only 1.5% of original grassland area) was contained in federal and state PAs in the entire state of Rio Grande do Sul. Designated PAs of the *Campos de Cima da Serra* contained larger proportions than these at the beginning of our study period, although forest was, overall, better represented in PAs than grassland. However, designation as Full Protection PA did not prevent conversion of grassland, and designation as Sustainable Use PA increased grassland conversion risk, in stark contradiction to the high standards of the Brazilian Protected Areas system and the IUCN recommendations for protected area management to which the Brazilian system corresponds (Silva 2005, Appendix S1: Table S2). In fully protected PAs at least, which correspond to IUCN categories II and Ia, conservation of native biodiversity must be given priority over land use. There are further striking trends. First, conversion to cropland predominated over conversion to tree plantations inside PAs, in contrast to conversion trends outside PAs, especially so in the Sustainable Use PA “Rota do Sol” (corresponding IUCN category V). Second, substantial proportions of grassland area of designated Full Protection PAs were lost not only to conversion but to succession to forest. Both of these apparent paradoxes reflect dilemmas of nature conservation.

In designated Full Protection areas, land acquisition by the government or, eventually, expropriation are mandatory (Federal Law number 9.985/2000). This process usually takes more than a decade to complete (D. Zimmermann and D. Slomp, *personal communication*; see also Silva 2005) and during this period of legal insecurity, landowners tend to overexploit the natural resources that motivated the creation of the PA (ibid., Rocha et al. 2010). Afterwards, when the land is state or national property, management for economic returns is prohibited. Cessation of grassland management inevitably results in accumulation of dead biomass, shrub encroachment, and a net loss of species per unit area (Koch et al., *unpublished manuscript*). Eventually, forest species can colonize these areas (Oliveira and Pillar 2004). Expansion of one endangered native ecosystem is achieved by failure to protect another. Miklin and Čížek (2014) report the same dilemma in conservation of open woodlands in an UNESCO Biosphere Reserve of the Czech Republic.

Predominance of agriculture over silviculture may indicate that environmental licensing of tree plantations was effective in regulating silviculture at least inside designated PAs. Re-establishment of grassland on former silviculture areas, although observed on a minor proportion of PA area, may also point to restrictive licensing. The LULC map of the state Rio Grande do Sul is being continuously updated by H. Hasenack and colleagues, and it is hoped that data from recent years—i.e., from 5 to 6 years after the implementation of environmental zoning for silviculture—will permit reliable statements about the effectiveness of this planning instrument. Unfortunately, a corresponding licensing procedure for agriculture did not exist at the time of this study. Nature conservation authorities were certainly placed in a weak position to prevent agricultural expansion especially in the neighboring ES- and EPA areas (Fig. 2) that already contained relatively large areas of agriculture at the beginning of this study.

The efficiency of Sustainable Use PAs in preserving natural vegetation types is a cause for concern; effective conservation risk for grassland was several times higher inside these areas than in areas without any designated protection status. The term “sustainable use” is broadly interpreted, as foreseen by Rylands and Brandon (2005). Do silviculture or agriculture, as practiced in the study region, guarantee long-term existence of renewable environmental resources and ecological processes, as is the legal definition of sustainable use in Brazil (Federal Law number 9.985/2000, Art. 2-XI)? Published case studies are as yet too fragmentary, limited in scope and contradictory in results to answer these questions (Andrade et al. 2015); in particular, no study has addressed the impacts of herbicide application on soil and water resources and living organisms, including livestock on intermittently grazed cropland.

The fact that neither of the two “National Forests” suffered a net loss in forest gives a distorted picture of forest conservation in SU-PAs. Specifically, most of the area of National Forest “Canela” was covered by artificial plantations, both in 2002/2003 and 2008/2009, and near equal proportions of these plantations were assigned to native and exotic species. Both National Forests within the study area previously belonged to the National Pine Institute (*Instituto Nacional do Pinho*), which created large areas of exotic tree plantations. This Brazilian official organ was founded in 1941 to protect the interests of producers and exporters of industrial pine (Federal law number 3.124, 1941, for the creation of the Brazilian National Pine Institute; http://www.planalto.gov.br/ccivil_03/decreto-lei/1937-1946/Del3124.htm). “National forests” are thus more appropriately regarded as national timber reserves.

The objective of Sustainable Use PAs is to make “nature conservation compatible with sustainable use” (Federal Law number 9.985/2000, for the creation of the Brazilian National System of Protected Areas, Art 7 §2; http://www.planalto.gov.br/ccivil_03/LEIS/L9985.htm), in line with the IUCN framework of nature conservation (Dudley 2008). However, Silva’s statement that sustainable use PAs allow for “varying forms and degrees of exploitation, with biodiversity protection as a secondary objective” (Silva 2005:608), is probably closer to reality.

In conclusion, designation of protected areas alone is not considered sufficient to preserve biological diversity. Strict protection, corresponding to IUCN category II, was found to be fairly successful at conserving native forest, at least relative to forest outside these PAs. Similarly, in a questionnaire-based study, parks >5,000 ha with strict protection status were judged mostly effective at preventing land clearing in tropical countries (Bruner et al. 2001). Naughton-Treves et al.’s (2005) meta-analysis also indicated better protection of forest inside than outside PAs; however, there is bias toward strictly protected areas in their data set which includes more than twice as many strictly protected forest PAs (IUCN categories I and II; 25 studies) than PAs of lesser protection status (11 studies). Of the former, 22 areas had less deforestation inside than outside PA borders, and of the latter, 9 of 11 areas, which supports the view that Full Protection status is more efficient than no protection, but does not conclusively establish the same effectiveness of lesser protected areas. Bruner et al. (2001) stated that strict protection effectiveness depends on density of guards and corresponding likeliness to detect illegal activities, with most efficient parks disposing of three guards per 100 km² at the time. This figure probably needs revision, as availability of high-quality remote sensing data at no cost on the World Wide Web is expected to facilitate PA monitoring nowadays. The statement that clear demarcation of borders and direct compensation to local communities and landowners further contributes to park effectiveness (Bruner et al. 2001) is expected to still hold true.

One drawback of both cited studies is that they do not compare effectiveness of protection inside PAs and in areas under private governance. Hayes (2006), by comparing forest density inside protected areas and areas under private governance, concluded that the former were not more efficient at protection than the latter; there was also indication that establishment of rules for forest exploitation by the users themselves (instead of or in addition to rules imposed by the government) correlated positively with forest density. Unfortunately, Hayes' study does not allow to distinguish between PAs with strict and with lesser protection status, and thus, to assess relative efficiency of the corresponding IUCN categories. Neither of the cited studies addresses conservation of non-forest vegetation.

Our study, although smaller in scope, stands out by permitting simultaneous comparison of LULC changes inside and outside areas with strict and with lesser protective status, and moreover, the assessment of conservation efficiency for both types of natural vegetation: Forest and grassland. It reveals, alarmingly, that neither Full Protection nor Sustainable Use PAs (corresponding to IUCN categories V and VI) contributed to grassland conservation during the study period, due to multiple reasons outlined above. For this type of vegetation, which is primary in southern America but nevertheless depends on management for biodiversity preservation, more might be gained by encouraging land use types that are sustainable in the sense of Brazilian law, be it through governmental aids or through participative planning and environmental education. The latter might improve broad scale appreciation of grassland as a natural resource; and the former might aid in establishing a diversified management to increase productivity and to preserve, at the same time, at least a major proportion of native species. Within the Grassland Conservation Program run by the US Department of Agriculture, for example, landowners have been remunerated for preservation of native grasslands and grazing management; the program has run for nearly 30 years and been judged an efficient tool for preservation of abiotic resources and wildlife (Vandever and Allen 2015), although the authors urge the USDA to make these results more publicly known in order to ensure support in the longer term.

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